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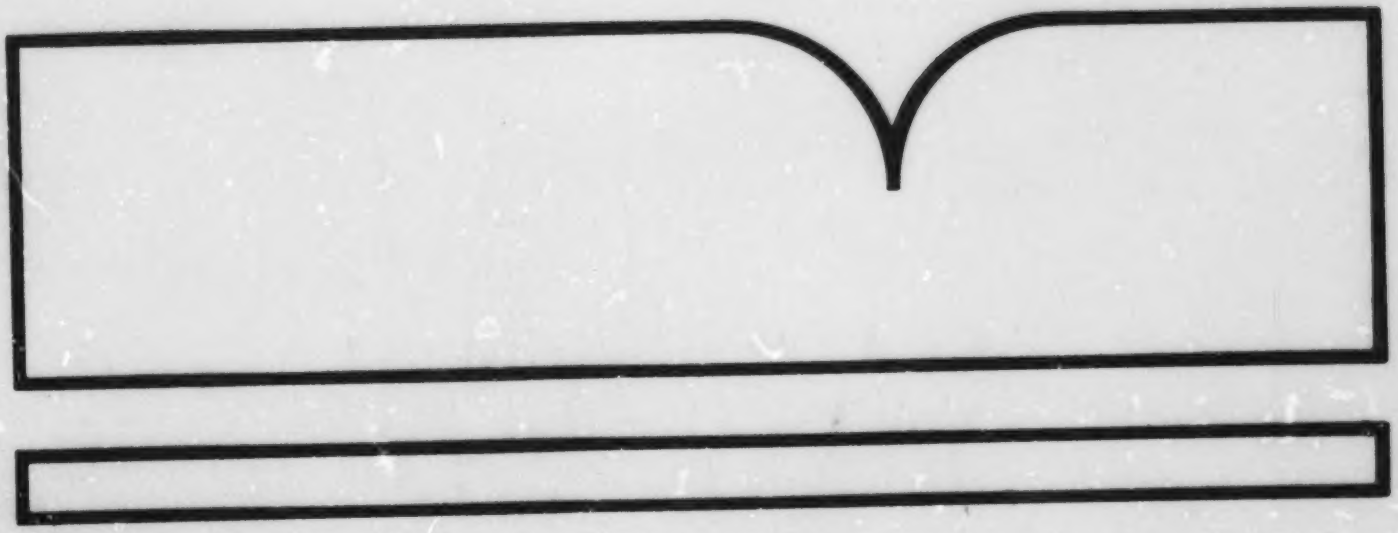
Infiltration and Permeability Testing at Geokinetics Oil Shale Site

Kaman Tempo, Santa Barbara, CA

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

Mar 84



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Infiltration (double-rint) and pressure permeability (packer) tests were conducted in or near true in-situ oil shale retorts and at adjacent undisturbed locations to obtain comparative data to evaluate the potential for groundwater pollution due to increased fluid migration resulting from this retorting methodology. Tests were performed at the Geokinetics oil shale site located in Section 2, Township 14 South, Range 22 East, Uintah County, Utah.

Test results suggest a slight increase in surface infiltration rates and hydraulic conductivity in or near the retort areas. This will allow additional surface waters to enter into and pass through the vadose zone increasing the possibility of contact with potential pollution sources generated by retorting activities. However, due primarily to the separation of the shallowest aquifer underlying the test site, 244 to 274 meters (800 to 900 feet) and the intervening rocks consisting of impermeable shale, marlstone, oil shale and tar sand, it is expected that this type of true in-situ retorting will pose very little, if any, threat to groundwater resources in the area.

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INFILTRATION AND PERMEABILITY TESTING AT GEOKINETICS OIL SHALE SITE

by

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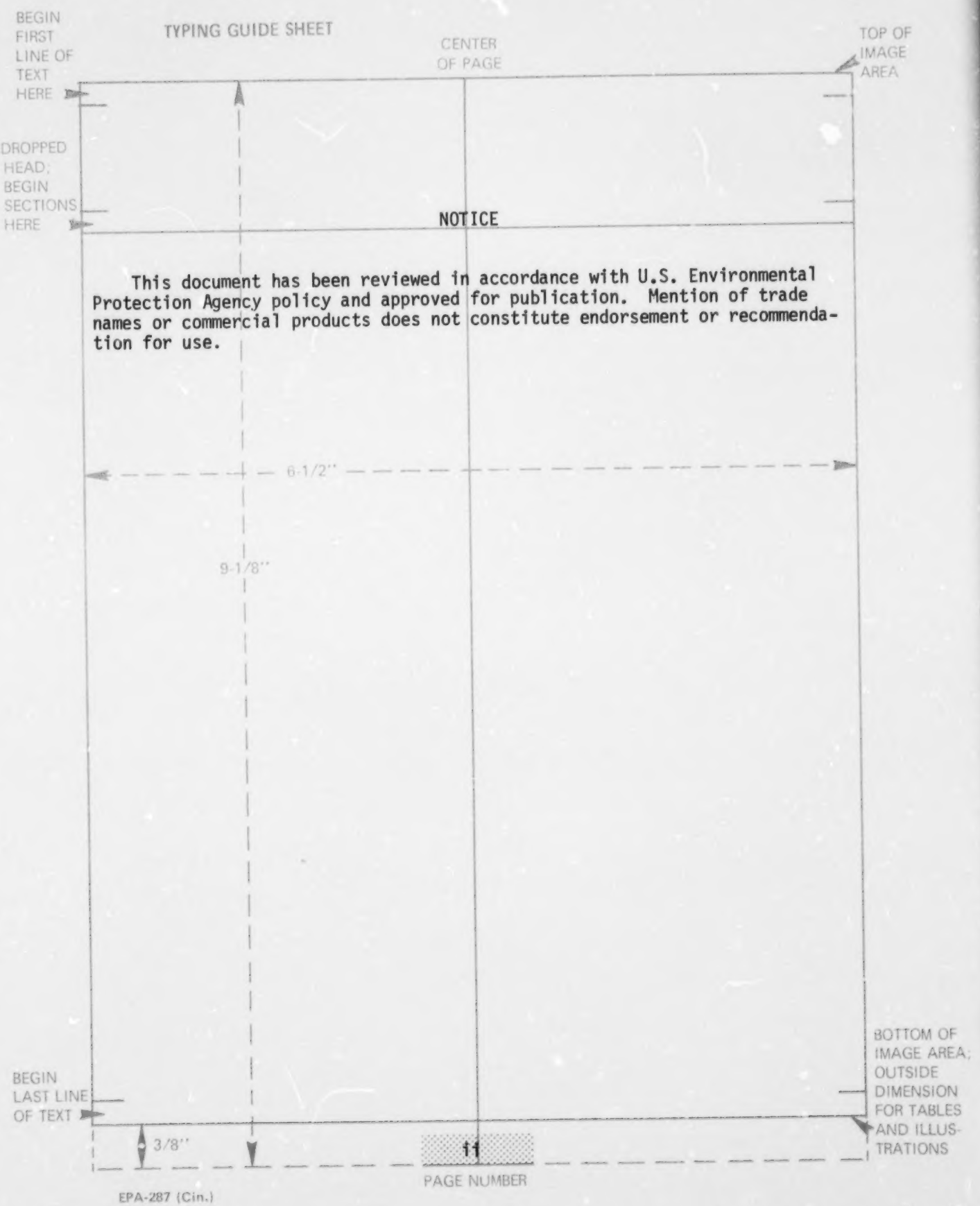
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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report summarizes infiltration and permeability testing conducted at the Geokinetics oil shale development site. The findings provide a basic assessment of the mechanisms by which true in-situ mining activities affect groundwater infiltration and migration through the vadose zone. An understanding of these mechanisms will help minimize adverse effects on groundwater resources. For further information, contact the Energy Pollution Control Division, Industrial Environmental Research Laboratory - Cincinnati.

David G. Stephan, Director
Industrial Environmental Research Laboratory
Cincinnati

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ABSTRACT

Infiltration (double-ring) and pressure permeability (packer) tests were conducted in or near true in-situ oil shale retorts and at adjacent undisturbed locations to obtain comparative data to evaluate the potential for groundwater pollution due to increased fluid migration resulting from this retorting methodology. Tests were performed by Kaman Tempo at the Geokinetics oil shale site located in Section 2, Township 14 South, Range 22 East, Uintah County, Utah.

Three infiltration test sites were selected for study. Two of the sites were located in disturbed surface soils overlying retorts numbered 14 and 15. The third site was situated in nearby undisturbed soils similar to those found at the two retorts. Infiltration rates above the retorts were similar to somewhat higher than those found at the undisturbed site. Variation in the final infiltration rates (after 90 minute tests) was slightly greater for the disturbed sites although not enough data was available to develop statistical comparisons of the range or rate of surface inflow.

Pressure permeability tests were conducted in the newly constructed angle Hole No. 1 and in the existing Core Hole No. 12. The angle hole was drilled so that permeability measurements could be made near and below burned retort 24. Hydraulic conductivity calculations for dual-packer settings at shallow 0 to 24 meters (0 to 80 feet) depths near the retort indicated that permeabilities were more uniform and slightly higher than in the undisturbed rocks. Test results suggest that hydraulic conductivity in the tight oil shale strata is controlled by secondary porosity i.e., fractures. Near the retort, fracture permeability was encountered throughout the upper part of the hole whereas 4 of the 7 test sections in the undisturbed formation would not take water. Unfortunately, permeability tests below the retort were hindered by a wax-like hydrocarbon that seeped into the hole between completion of drilling and packer testing.

Test results suggest a slight increase in surface infiltration rates and hydraulic conductivity in or near the retort areas. This will allow additional surface waters to enter into and pass through the vadose zone increasing the possibility of contact with potential pollution sources generated by retorting activities.

However, before drawing any conclusions regarding the extent of threat to groundwater resources in the area, the hydrogeologic conditions, especially permeability of the stratigraphic interval between the retorts and the closest aquifer should be carefully defined. At the test site this interval consists of several hundred feet of shale, marlstone, oil shale and tar sand. Although these lithologies normally have very low permeability, any secondary

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permeability introduced by fracturing or jointing must be defined before concluding that a significant threat to groundwater resources does or does not exist. Extrapolation of results from this study to other sites is valid only to the extent that retorting and hydrogeologic conditions can be defined to be the same as for this test site.

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Mr. Leslie G. McMillion
Mr. Edward R. Bates

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Mr. M.A. Lekas
Mr. J.M. Lekas
Mr. W.L. Sharrer
Mr. M. Leschin

SECTION 1

INTRODUCTION

This report discusses the results of Kaman Tempo's infiltration and permeability testing at the Geokinetics oil shale site located in Section 2, T14S, R22E, Uintah County, Utah (Figure 1). Comparative evaluations for each of the testing methods were performed in areas affected and unaffected by retort development. All work performed herein was conducted pursuant to EPA Contract No. 68-03-2449.

The objectives of this research program were to: (1) evaluate possible alteration of surface infiltration rates due to retort development, burning and associated surface fracturing and uplift; and (2) to measure, by means of packer testing, possible changes in the permeability of rocks affected by retort development and burning.

The Geokinetics site was selected for testing because of the true in-situ oil shale retorting methodology utilized there, see Figure 2. In this process, initial start-up costs are relatively low and time to bring production on line is short. The process entails drilling a pattern of drill holes from the surface, through the overburden and into the oil shale bed. The holes are loaded with explosives and fired, using a pre-determined blast system. The blast results in a fragmented mass of oil shale with high permeability. The void space in the fragmented zone comes from lifting of the overburden that produces a small arch in the ground surface.

The fragmented zone within the oil shale horizon constitutes an in-situ retort. The bottom of the retort is sloped to facilitate drainage of the oil to a sump where it is lifted to the surface by a number of oil production wells. Air injection holes are drilled at one end of the retort, and off-gas holes are drilled at the other end. The oil shale is ignited at the injection wells. Air is then injected to establish and maintain a burning front that occupies the full thickness of the fragmented zone. The front is moved in a horizontal sweep through the fractured shale towards the off-gas wells at the far end of the retort. The hot combustion gases from the burning front heat the kerogen in the oil shale inducing destructive distillation and driving out the oil. The oil drains to the bottom of the retort, where it flows along a sloping surface to the oil production wells. As the burn front moves from the air-in to the off-gas wells, it burns the residual carbon in the retorted shale as fuel. The combustion gases are recovered at the off-gas wells. This gas is combustible and can be used for power generation.

This process has been applied to areas where the overburden is relatively thin. Retorts have effectively been blasted with 17 meters (55 feet) of

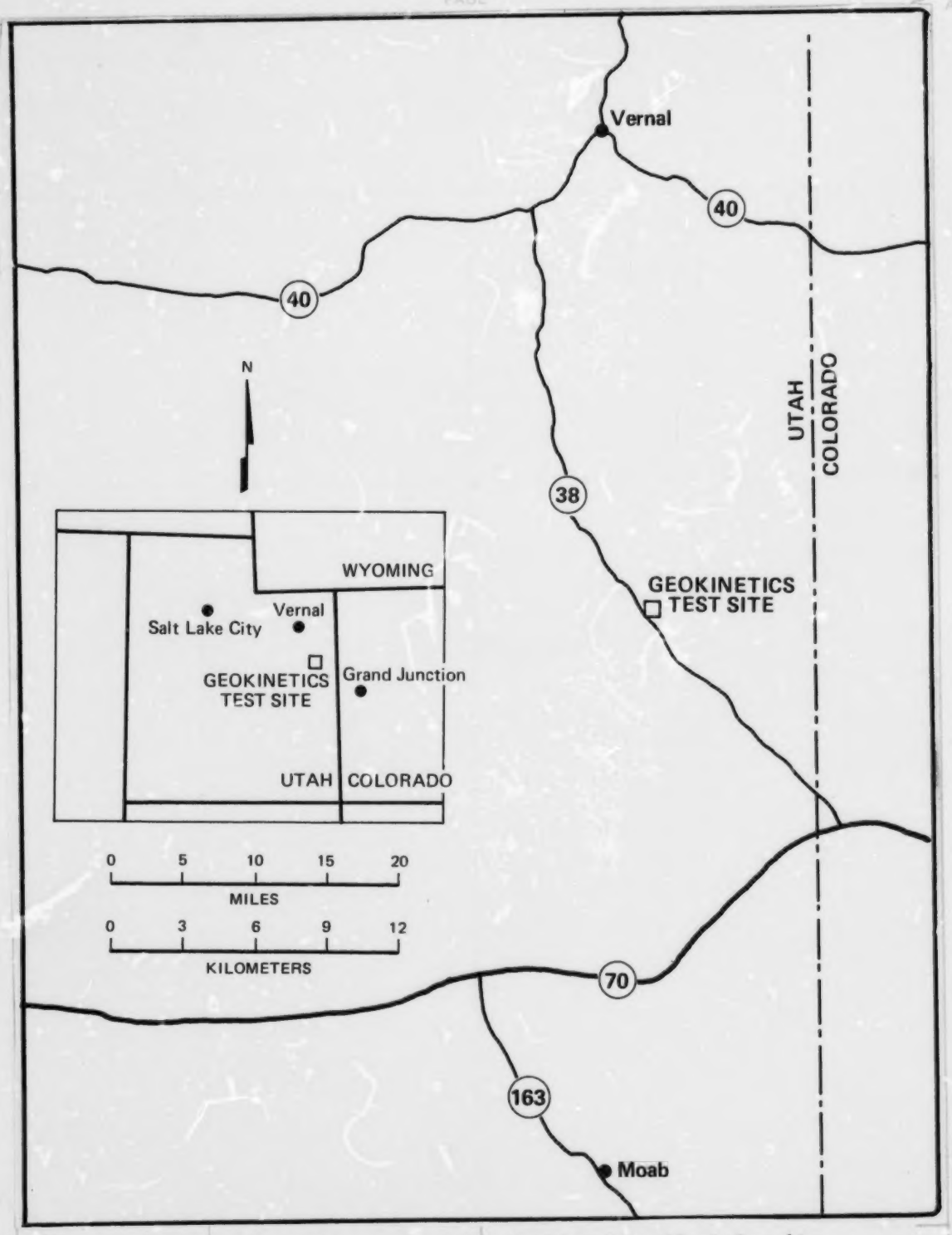

Figure 1. Location map of the Geokinetics oil shale site

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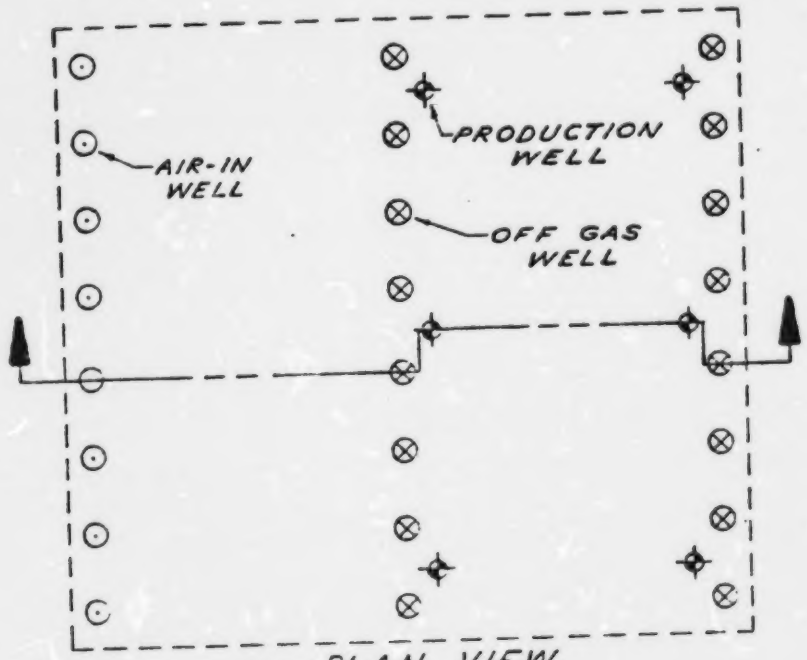

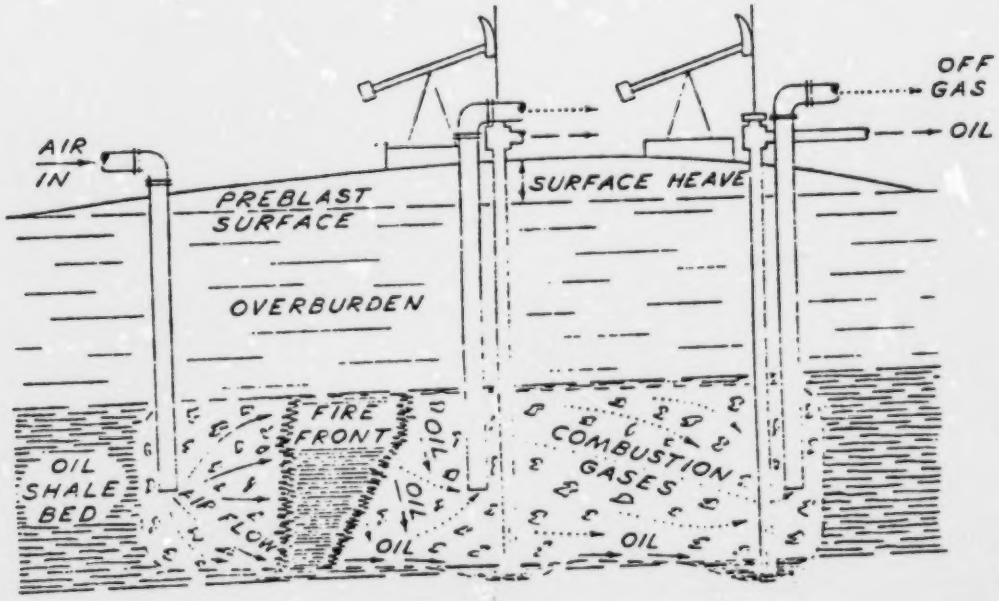

Figure 2. Plan and section views of a true in situ retort

overburden. Geokinetics has been conducting tests to determine the maximum acceptable limit of overburden thickness.

Since the beginning of Geokinetics' development program in 1975, a total of 26 test retorts have been fractured to develop blasting methods and retorting parameters and procedures. In testing these retorts, 4,770 cubic meters (30,000 barrels) of shale oil have been produced. Three full-sized retorts have been blasted, measuring 65 meters (214 feet) by 70 meters (230 feet), with a 9 meter (30 foot) average thickness of oil shale.

A commercial operation would consist of a number of such retorts burning at the same time with each producing from 16 to 32 cubic meters (100 to 200 barrels) per day. Each retort would have a life span of six to eight months with an estimated production of 2,385 to 3,975 cubic meters (15,000 to 25,000 barrels) of oil. A self-contained production unit would produce from 318 to 795 cubic meters (2,000 to 5,000 barrels) of oil per day.

This study has tested infiltration and permeability characteristics of soil and rock formations at the Geokinetics' oil shale retorting facilities. Extrapolation of results from this study to other sites is valid only to the extent that retorting and hydrogeologic conditions can be defined to be the same as for this test site. The report is divided into four sections including the Introduction. Section 2 describes the infiltration and permeability testing program. Section 3 discusses the test results with general conclusions provided in Section 4.

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SECTION 2

TESTING PROGRAM

Kaman Tempo performed the infiltration and permeability testing at the Geokinetics site during September and October, 1981. Autumn was selected for testing in order to avoid water saturated soil conditions resulting from spring snow melt and summer thunder storms. Frozen soil conditions and access problems of winter were likewise avoided.

Infiltration Testing

Double-ring infiltration tests were performed at nine location -- six overlying retort areas and three in undisturbed areas. The purpose of the study was to evaluate changes in infiltration rates due to surface heave over the retorts. Double-ring infiltrometers were selected because they provide data that is considered representative of the vertical component of the infiltration flow, and for their operational simplicity in the field that facilitated multiple tests for comparative analysis.

Care was taken to conduct all infiltration tests on the same soil type; namely, Luhon Loam. This unit consists of deep, well drained soils formed from mixed alluvium and in residuum from Green River shale Luhon soils occur on gently sloping to gently rolling fans and valley side slopes. Present native vegetation is mainly big sagebrush, (Artemisia Tridentata) four-wing saltbush, (Atriplex Canescens) winterfat, (Ceratoides lanata), western wheatgrass, (Agropyron smithii), blue grama grass, (Bouteloua gracilis), and bluebunch wheatgrass (Agropyron spicatum).

In a typical profile the surface layer is a pale brown, silty clay loam about 23cm (9 in) thick. The substratum consists of about 18cm (7 in) of very strongly calcareous loam underlain by gravelly loam. (The gravelly loam is about 90 percent soft, weathered shale fragments; about 60 percent of these shale fragments slake when soaked in water.)

Representative Profile:

- A1 0-18cm (0-7 in), pale brown (10YR 6/3) loam brown (10YR 4/3) moist; weak medium subangular-blockly structure; hard friable; non-sticky and slightly plastic; strongly calcareous, moderately alkaline; clear, smooth boundary.

- B2 18-41cm (7-16 in), very pale brown (10YR 7/4) silty-clay loam yellowish-brown (10YR 5/4) moist; moderate, medium angular-blocky

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structure; very hard, firm; slightly sticky and plastic; very strongly calcareous, strongly alkaline; gradual wavy boundary.

- C1 41-58cm (16-23 in) light gray (10YR 7/2) loam, pale brown (10YR 6/3) moist; weak medium subangular-blocky structure; slightly hard, very friable; non-sticky and slightly plastic; strongly calcareous, strongly alkaline; gradual wavy boundary.

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- 11 C2 58-152cm (23-60 in) light gray (10YR 7/3) gravelly loam, brown (10YR 5/3) moist; (this gravelly loam is about 90 percent soft, weathered shale; about 60 percent shale fragments slake when soaked in water); strongly calcareous and strongly alkaline.

- Pit Location: 183m E(600 ft) and 610m S(2,000 ft) of NW corner of Section 2, T14S, R22E, Uintah County, Utah.

- This soil is in the semi-desert loam, summer precipitation range site.

The test procedure at all sites was conducted in the following manner: A metal cylinder 30cm (12 in) in diameter was driven to a depth of approximately 15cm (6 in) into the soil at the test site. A larger cylinder, 46cm (18 in) in diameter, was placed concentrically around the 30cm (12 in) cylinder. The areas within the inner and outer cylinders were flooded and the rate of recession of the water level in the inner ring was measured by means of a meter staff. Tests were conducted for 90 minutes, which in the soil type tested was considered sufficient time to obtain a steady state condition.

The infiltration rate is controlled by the least-permeable zone in the subsurface soils. The double-cylinder infiltrometer is used to help prevent divergent flow in layered soils by providing an outer water barrier to encourage only vertical flow from the inner ring. Other factors affect the infiltration rate in addition to the soil structure, for example, the condition of the soil surface, the moisture content of the soil, the chemical and physical nature of the soil and of the applied water, the head of applied water, and the temperature of the water. Thus, tests made at the same site are not likely to give identical results. Accordingly, the rates measured by the cylinder-type procedure in this testing program are for comparative use only.

Tests were conducted over burned retorts 14 and 15. These retorts cover approximately 223 and 325 square meters (2,400 and 3,500 sq. feet), respectively.

It is generally acknowledged that infiltration rates determined by sprinkling a large area are more reliable than cylinder-type determinations. However, the need for multiple test sites and the high cost of utilizing sprinkler infiltrometers precluded their use during this study.

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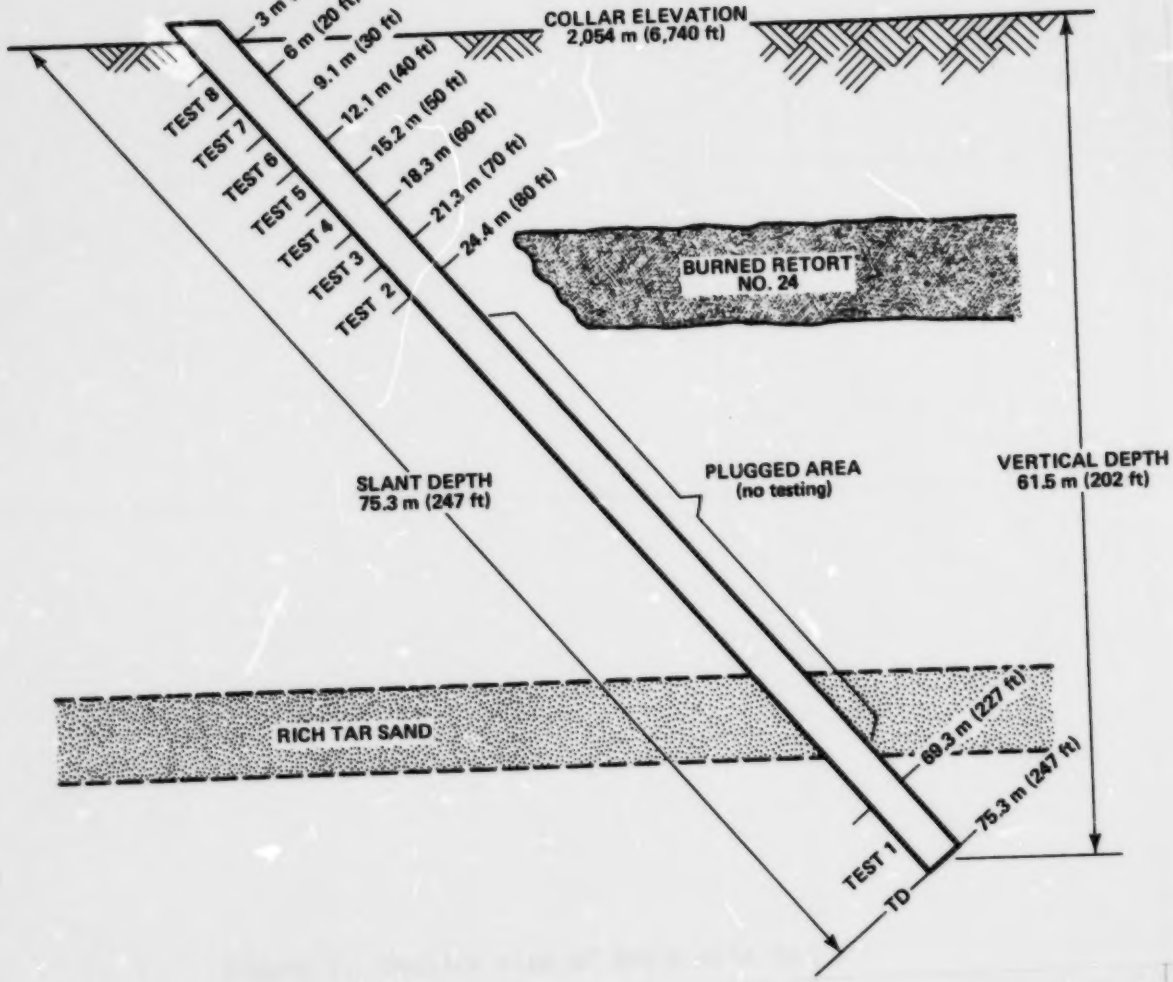

Figure 3. Section view of Angle Hole No. 1

Pressure Permeability Testing

Pressure permeability tests were conducted in two drill holes. Angle Hole No. 1 was drilled between retort 24 (burned) and retort 26 (unburned) in a manner so that it would pass within 3 meters (10 feet) of the base of the burned core of retort 24 (Figure 3) and bottom approximately 38 meters (124 feet) below the base of the retort. Total length of this hole is 75 meters (247 feet). (Permeability testing could not be done in any of the burned retorts because of residual high rock temperature and very high permeability). The other drill hole tested was Core Hole 12, drilled in 1978 by Geokinetics. This hole is vertical, was found to be in good condition and was suitable for testing. It is 30 meters (100 feet) deep and is not located near rubblized or retorted strata. Both holes are NX 7.6cm (3 inch) diameter and are bottomed above the water table. The shallowest substantial aquifer underlying the Geokinetics site is the Douglas Creek Member of the Green River Formation, approximately 244 to 274 meters (800 to 900 feet) below the surface.

Dual-packers spaced 3.6 meters (11.8 feet) apart were placed on the end of the drill string. Subtracting the space occupied by the packers, this resulted in testing a 3 meter (10 foot) interval. Testing started at the bottom of each hole and progressed upward at intervals approximately equal to the packer spacing. Testing and calculation of permeability for each zone were done in accordance with the method discussed in Ground Water Manual published by the U.S. Department of the Interior, Bureau of Reclamation, 1977. Copies can be obtained from the Bureau's Engineering and Research Center, P.O. Box 25007, Denver Federal Center, Denver, Colorado 80225, Stock #024-003-00106-6.

SECTION 3

INFILTRATION AND PERMEABILITY TEST RESULTS

Infiltration

Infiltration rates expressed in centimeters per hour were calculated directly from field measurements. These data are given in Table 1. Infiltration rates were plotted against time, resulting in curve showing the change in tendency of the soil to absorb water with time, see Figure 4. The area under the curves represent the infiltration capacity or the capacity of the soil to absorb water up to a particular time.

Results of the infiltration tests indicate moderate to slow infiltration rates. Infiltration rates were slower in the undisturbed area than over both retorts, but the retort rates are still considered to be slow. All plots indicate roughly the same attainment of near-steady state conditions.

On the basis of eight tests there were no statistically significant differences in the surface infiltration rates. The ninth test (site c, retort 14) was not included in the analysis. The heavy vegetative cover producing extensive root structure within the tested soil horizon provided pathways for the infiltrating water thus giving nonrepresentative results. From the limited amount of data developed the range of final infiltration rates appeared somewhat larger overlying the retorts as compared to the undisturbed area. However, no statistical significance could be developed for this apparent characteristic nor for the slightly higher overall infiltration rates found overlying the retorts.

Permeability

Angle Hole No. 1. This hole was utilized to evaluate permeability near a burned retort, and in the area underlying the retort, see Figure 3. During the drilling of the hole, 7.6 meters (25 feet) of rich tar sand was encountered at approximately 59m (195 feet), see lithologic log, Appendix A. Between completion of the hole and packer testing a substantial amount of wax-like hydrocarbon material had seeped into the well bore and drill string clogging 30m (100 feet) of drill pipe. This prevented testing of the interval between 24m and 69m (80 feet to 227 feet). A single packer test was conducted between 69 meters and the bottom of the hole at 75 meters (227 and 247 feet). Double packer tests were conducted at 3 meters (10 foot) intervals from 24 to 3 meters (80 feet to 10 feet).

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Table 1. Infiltration measurements

	Time	Min	CM	CM/HR	
RETORT 15					
Site A	10:25	0	17.0	--	
	10:30	5	21.3	52	
	10:35	10	22.9	18	
	10:40	15	23.4	7	
	10:45	20	24.0	7	
	10:55	30	24.8	5	
	11:15	50	26.1	4	
	11:45	80	27.5	3	
	11:55	90	27.9	2	
Site B	12:07	0	17.4	--	
	12:12	5	19.5	25	
	12:22	15	22.3	17	
	12:42	35	25.9	11	
	1:12	65	27.7	7	
	1:37	90	30.5	5	
Site C	1:52	0	16.0	--	
	1:57	5	19.9	47	
	2:27	35	23.6	13	
	2:57	65	28.0	8	
	3:22	90	32.0	7	
RETORT 14					
Site A	3:43	0	16.5	--	
	3:48	5	18.4	23	
	3:58	15	20.3	11	
	4:08	25	21.5	7	
	4:28	45	23.8	7	
	4:48	65	25.9	6	
	5:13	90	28.0	5	
Site B	5:22	0	18.7	--	
	5:27	5	21.5	37	
	5:37	15	24.5	18	
	5:57	35	26.5	6	
	6:22	60	28.6	5	
	6:52	90	30.5	4	
Site C	9:07	0	19.5		--
	9:12	5	28.0		142
	9:22	15	30.5	(refill)	42
	9:42	35	dry		27

Table 1. Infiltration measurements (Con't)

	Time	Min	CM	CM/HR
UNDISTURBED AREA				
Site A	11:05	0	17.0	--
	11:10	5	18.5	18
	11:20	15	20.0	9
	11:35	30	21.5	6
	12:05	60	23.5	5
	12:35	90	25.6	4
Site B	12:42	0	17.4	--
	12:47	5	18.8	17
	12:52	10	19.3	6
	12:57	15	20.0	8
	1:12	30	21.0	4
	1:42	60	22.5	3
	2:12	90	23.4	2
Site C	2:35	0	16.5	--
	2:40	5	18.0	18
	2:50	15	20.0	12
	3:05	30	22.1	8
	3:35	60	24.5	5
	4:05	90	26.4	4

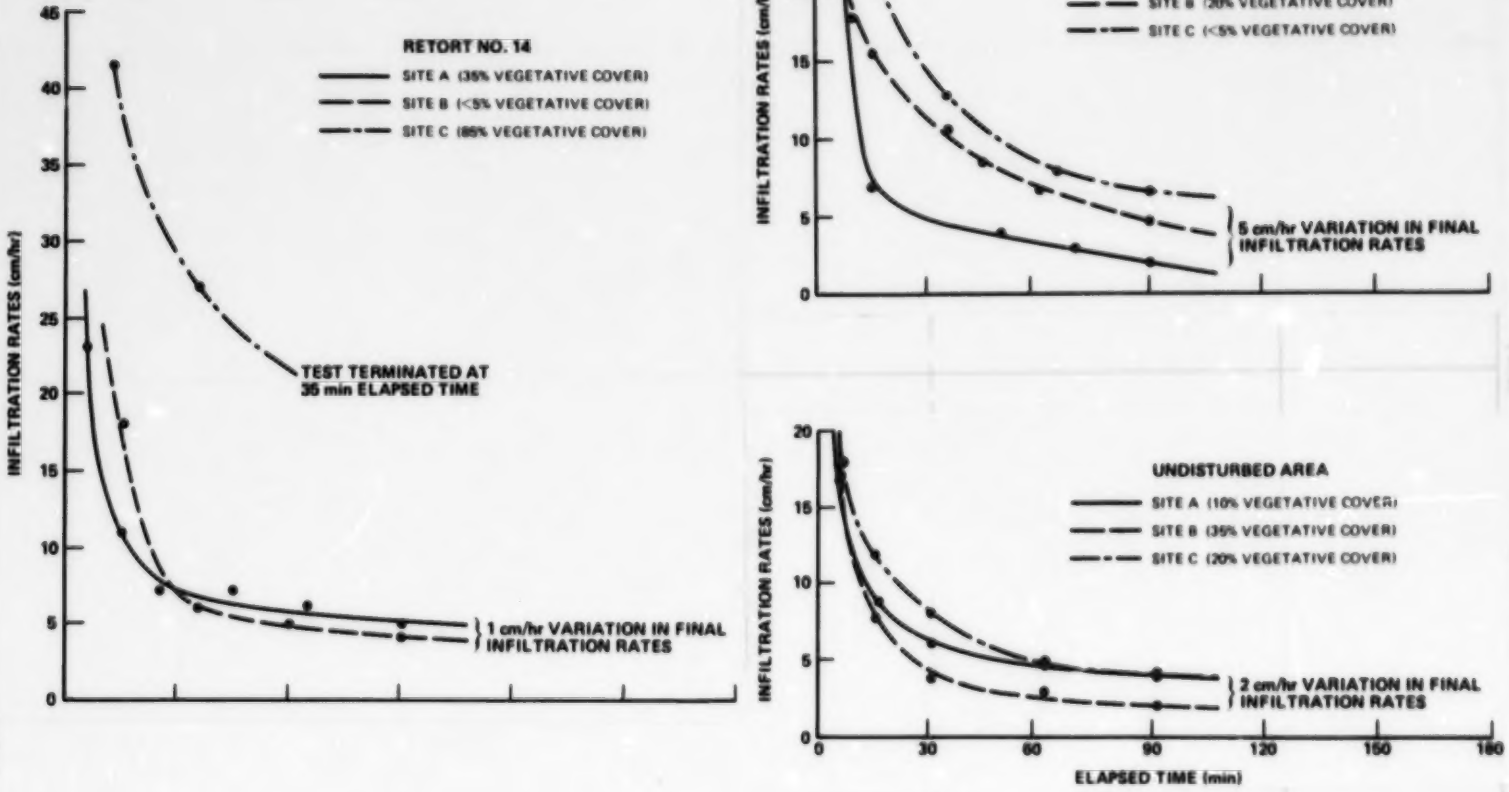
RETORT NO. 14
SITE A (35% VEGETATIVE COVER)
SITE B (<5% VEGETATIVE COVER)
SITE C (85% VEGETATIVE COVER)
INFILTRATION RATES (cm/hr)
TEST TERMINATED AT 35 min ELAPSED TIME
1 cm/hr VARIATION IN FINAL INFILTRATION RATES
RETORT NO. 15
SITE A
SITE B (20% VEGETATIVE COVER)
SITE C (<5% VEGETATIVE COVER)
5 cm/hr VARIATION IN FINAL INFILTRATION RATES
UNDISTURBED AREA
SITE A (10% VEGETATIVE COVER)
SITE B (35% VEGETATIVE COVER)
SITE C (20% VEGETATIVE COVER)
2 cm/hr VARIATION IN FINAL INFILTRATION RATES
ELAPSED TIME (min)

Figure 4. Plots of infiltration rates for retorts 14, 15 and undisturbed area

Core Hole 12. This existing hole was found to be in good conditio for testing and did not penetrate the tar sand found deeper in Angle Hole No. 1. Located 304 meters (1,000 feet) from the nearest retort it was selected to provide hydraulic conductive data for undisturbed material. Unfortunately, core unavailability prevented construction of a structure log, but a lithologic log is given in Appendix B.

Dual-packer permeability tests were run throughout Angle Hole 1, Figure 5, and Core Hole 12 except for a single packer test run at the bottom of Angle Hole 1. Hydraulic conductivity (K) has been determined using the method presented in the Bureau of Reclamation publication cited earlier. In using this method the zone within which the test section is located and the conductivity coefficient (Cu) must be determined. The zone 1/zone 2 boundary is defined on a graph relating percentage of unsaturated stratum (X) and the distance from the water surface in the well to the water table (Tu) divided by the length of the test section (A), see B. Rec. 1977 Figure 10-6, page 261. To define these parameters the following information is needed:

- o Depth to the water table (U) in meters
- o Distance (D) from the ground surface to the bottom of the test section, i.e., lower packer in meters
- o Total head (H) comprised of the static head (h1) and the effective head (h2), i.e., gage pressure converted into height in meters
- o length of the test section (A) in meters

where: $X = (H/Tu)(100)$ and $Tu = U - D + H$

All the test sections were located in zone 1. The hydraulic conductivity for this zone is defined by equation 1 and given in Table 2.

$$K = Q/ (Cu)(r)(H) \quad \text{.....1}$$

where:

Q equals the flow rate into the formation in cubic meters per second

Cu equals a dimensionless conductivity coefficient

r equals the radium of the bore hole in meters

The conductivity coefficient is taken from B. Rec. (1977), Figure 10-7, page 262 and is dependent on r, H, and A. Sample calculation for a dual-packer test (No. 2, 21.3 to 24.4 meters (70-80 feet)) conducted in Angle Hole 1 are given below. Parameters used in the calculation of K for the remaining test sections are given in Appendix C.

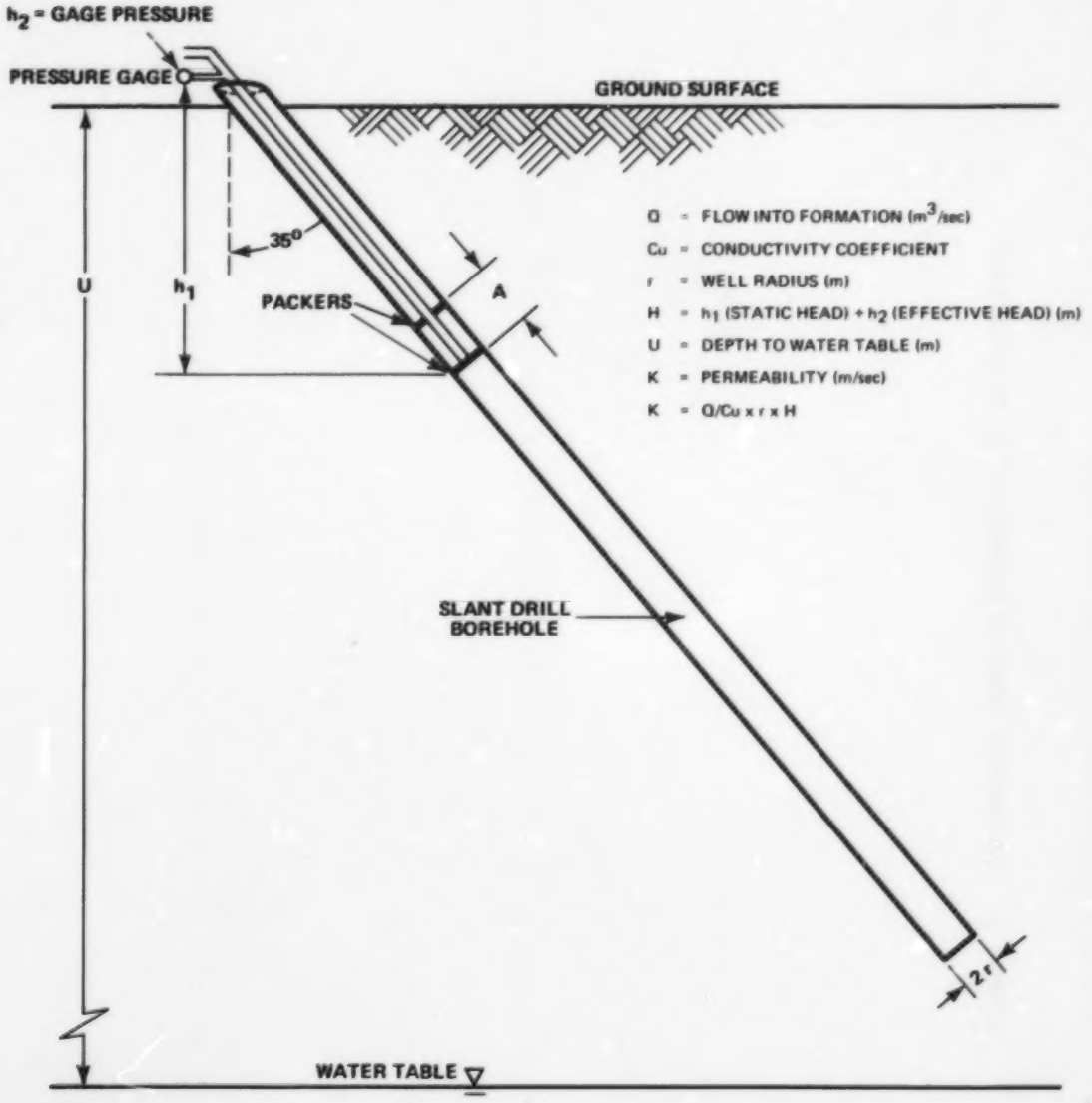

Figure 5. Parameters used in permeability calculations

Table 2. Permeability values for Angle Hole No. 1 and Core Hole 12

Test No.	Angle(m)	Angle(ft)	Vertical(m)	Vertical(ft)	K(m/sec)	K(ft/sec)
Angle Hole 1[a]						
1	69.2-75.3	(227-247)	56.7-61.6	(186-202)	3.6×10^{-9}	1.2×10^{-8}
2	21.3-24.4	(70-80)	17.4-20.1	(57-66)	2.3×10^{-6}	7.7×10^{-6}
3	18.3-21.3	(60-70)	14.9-17.4	(49-66)	2.7×10^{-6}	9.0×10^{-6}
4	15.2-18.3	(50-60)	12.5-14.9	(41-49)	4.6×10^{-6}	1.5×10^{-5}
5	12.2-15.2	(40-50)	10.1-12.5	(33-41)	4.9×10^{-6}	1.6×10^{-5}
6	9.1-12.2	(30-40)	7.6-10.1	(25-33)	1.2×10^{-5}	3.9×10^{-5}
7	6.1-9.1	(20-30)	4.9-7.6	(16-25)	9.3×10^{-6}	3.0×10^{-5}
8	3.0-6.1	(10-20)	2.4-4.9	(8-16)	Leaky Packer	
Core Hole 12[b]						
1			27.4-30.5	(90-100)	7.3×10^{-8}	2.4×10^{-7}
2			24.4-27.4	(80-90)	1.5×10^{-8}	5.0×10^{-8}
3			21.3-24.4	(70-80)	0	0
4			18.3-21.3	(60-70)	0	0
5			15.2-18.3	(50-60)	3.0×10^{-6}	1.0×10^{-5}
6			12.2-15.2	(40-50)	3.7×10^{-7}	1.2×10^{-6}
7			9.1-12.2	(30-40)	0	0
8			6.1-9.1	(20-40)	0	0
9			3.0-6.1	(10-20)	Leaky Packer	

[a] Elevation: 2054m(6740 feet)
Bearing: N58°30'W
Location: 4373N, 1810W

[b] Elevation: 2056m(6747 feet)
Location: 3788N, 2069E

U = 219.4 meters (720 feet)

D = 20.1 meters (66 feet)

A = 3.05 meters (10.0 feet)

r = 0.04 meters (0.125 feet)

h1 = 21.3 meters (70 feet)

h2 = 42.4 meters (139 feet)

Q = 0.001 m3/sec (0.04 ft3/sec)

H = 21.3 + 42.4 = 63.7 meters (209 feet)

Tu = U - D + H = 219.4 - 20.1 + 263 meters (862.9 feet)

x = (HTu)(100) = (66.8/263)(100) = 25.4%

Tu/A = 263/3.05 = 86.2

Zone 1 conditions from BLM plot

H/r = 66.8/0.04 = 1670

A/H = 3.05/66.8 = 0.05

Cu ~ 200 (from BLM Ground Water Manual, 1977)

$K = Q / (Cu)(r)(H) = 0.001 / (200)(0.04)(63.7) = 2.33 \times 10^{-6}$ m/sec

7.66×10^{-6} ft/sec

Permeability measurements show a good correlation with rock discontinuities developed from core analysis and given in Appendix D entitled Structure log of rock discontinuities. The correlation of permeability and secondary porosity (rock fractures) indicates that flow through the tight oil shale stratigraphy in this area is largely controlled by these discontinuities. Permeabilities varied by a factor of 1,000 from nearly impermeable rock at the bottom of the angle hole to moderately fractured rock near the surface. Conductivity values decrease very slightly as the angle hole approached the burned retort 24.

In general, permeability values were lower in the undisturbed area 304 meters (1,000 feet) southeast of the nearest retort. This is more apparent when you consider that 4 of the 7 tests sections in the undisturbed area would not take water at all. However, where fractures were penetrated permeability values were similar to or higher than those found near the retort.

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SECTION 4

CONCLUSIONS

Surface infiltration and pressure permeability tests have been conducted at the Geokinetics oil shale site. Eight double-ring infiltration tests suggest that there is a slight increase in fluid entering the soil profile over the retorts compared to undisturbed areas. However, the statistical significance of this apparent characteristic could not be evaluated with the limited data compiled herein.

Pressure permeability tests near retort 24 indicated an overall increase in hydraulic conductivity adjacent to burned/uplifted retorts compared with the undisturbed area. Although permeability values varied over a wider range in the undisturbed area (both higher and lower conductivity measurements recorded) several tests sections would not take water at all. This suggests that permeability is controlled by secondary porosity (rock fractures) that are enhanced by mining operations.

Surface infiltration and near surface permeability are the principal parameters that govern shallow fluid migration at Geokinetics' test site. Increased penetration of surface water and enhanced migration through the vadose zone increase the possibility of contact with and leachate generation from potential pollution sources generated by the mining and retorting activities. These fluids, should they reach the saturated zone, would have a negative impact on local groundwater quality.

However before drawing any conclusions regarding the extent of threat to groundwater resources in the area, the hydrogeologic conditions, especially permeability of the stratigraphic interval between the retorts and the closest aquifer should be carefully defined. At the test site this interval consists of several hundred feet of shale, marlstone, oil shale and tar sand. Although these lithologies normally have very low permeability, any secondary permeability introduced by fracturing or jointing must be defined before concluding that a significant threat to groundwater resources does or does not exist. Extrapolation of results from this study to other sites is valid only to the extent that retorting and hydrogeologic conditions can be defined to be the same as for this test site.

The study described herein has been very limited in scope. There is need for additional infiltration and permeability testing to provide better statistical control and it is hoped that these data would be generated as part of additional hydrogeologic work conducted at the site.

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APPENDIX A

LITHOLOGIC LOG ANGLE HOLE NO. 1

ANGLE HOLE NO. 1: 35° from Vertical
ELEVATION: 6740 Bearing N58°30'W
LOCATION: 4373N, 1810W

GEOLOGIST: G. W. Quinn
DRILLER: Steve's Drilling
DATE: 10/13/81 - 10/15/81

CORE INTERVAL (FT)	RECOVERY	DESCRIPTION
0 - 10.0		Rotary through shale Set 3" surface casing
10.0 - 18.8	100% - 8.8'	10.0 - 12.2 lean oil shale - grayish, yellowish brown. Moderately distinct to faint, thin to very fine laminae
		12.2 - 13.1 lean oil shale/marlstone moderate olive gray
		13.1 - 18.8 as above with thin limonite stained streaks
18.8 - 28.0	100% - 10.0'	18.8 - 26.0 oil shale, olive gray
		26.0 - 28.0 oil shale, olive, grayish brown with thinly bedded lt. gray tuff beds and thin tuff blebs and lenses
28.0 - 38.0	100% - 10.0'	28.0 - 30 as above. Alpha marker @ 29.7'
		30 - 38.0 oil shale, dark to moderate grayish brown, well laminated
38.0 - 48.0	100% - 10.0'	oil shale/marlstone, moderate olive gray
48.0 - 58.0	100% - 10.0'	marlstone, olive gray - lt. gray tuff - mahogany marker @ 53.3'
58.0 - 68.0	100% - 10.0'	58.0 - 59.1 marlstone, olive gray
		59.1 - 60.5 oil shale, moderate olive gray
		60.5 - 68.0 oil shale - rich - dusky, yellow, brown
68.0 - 78.0	100% - 10.0'	68.0 - 78.0 oil shale - rich dusky, yellow, brown
78.0 - 87.0	100% - Cut 9.0'	78.0 - 86.4 oil shale, as above
		86.4 - 86.5 tuff - lt. gray

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APPENDIX A

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CORE INTERVAL (FT)	RECOVERY	DESCRIPTION
		86.5 - 87.0 oil shale - lt. olive gray to dusky yellowish brown
87.0 - 97.0	100% - 10.0'	87.0 - 97.0 oil shale as above
97.0 - 101.0	100% - 10.0'	97.0 - 107.0 marlstone - lt. olive gray
107.0 - 117.0	100% - 10.0'	107.0 - 115.0 marlstone as above
		115.0 - 117.0 marlstone, lt. olive gray to grayish olive green
117.0 - 127.0	100% - 10.0'	117.0 - 127.0 as above
127.0 - 137.0	100% - 10.0'	127.0 - 132.2 marlstone, grayish, olive green
		132.2 - 133.0 shale, greenish gray
		133.0 - 135.6 marlstone, greenish gray dusky yellowish brown, 135 - 135.6
		135.6 - 137.0 tuff - yellowish gray - well developed loop structures
137.0 - 147.0	100% - 10.0'	137.0 - 139.7 shale, moderate olive gray, well developed laminae
		139.7 - 139.9 tuff, light gray
		139.9 - 140.1 shale, dusky yellowish brown
		140.0 - 140.8 tuff lt. gray
		140.8 - 146.4 shale/marlstone - light olive gray with thin interbedded tuff beds
		146.4 - 147.0 tar sand - moderate yellow brown, fine, angular, sand fragments in bitumin matrix
147.0 - 157.0	100% - 10.0'	147.0 - 149.2 tar sand as above
		149.2 - 151.8 tuff, light brownish gray
		151.8 - 157.0 marlstone, moderate gray green, well developed laminae

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APPENDIX A

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CORE INTERVAL (FT)	RECOVERY	DESCRIPTION
157.0 - 167.0	100% - 10.0'	157.0 - 161.4 marlstone as above
		161.4 - 162.8 brecciated tuff, yellowish gray
		162.8 - 167.0 shale, light grayish green
167.0 - 177.0	100% - 10.0'	160 - 170.0 shale as above
		170.1 - 170.7 tuff, olive gray
		170.7 - 173.9 shale, white to lt. brown to gray green, well laminated
		173.9 - 175.9 tuff, white to lt. gray brown
		175.9 - 177.0 shale, moderate olive gray
		177.0 - 177.2 tuff, light gray
		177.2 - 177.0 shale, lt. brown, well laminated
177.0 - 187.0	100% - 10.0'	177.0 - 179.0 tuff, lt. gray green to lt. tan
		179.0 - 179.6 shale, lt. brown
		179.6 - 185.9 tar sand, lt. yellowish gray to yellowish brown
		185.9 - 187.0 tuff, lt. gray
187.0 - 197.0	100% - 10.0'	187.0 - 189.0 tuff, lt. gray
		189.0 - 193.0 tar sand, moderate yellowish brown, fine-medium grained
		193.0 - 193.4 tuff, gray green
		193.4 - 194.0 tar sand, moderate yellowish brown, fine-medium grained
		194.0 - 195.4 tuff, gray green
		195.4 - 197.0 rich tar sand, olive gray
197.0 - 207.0	100% - 10.0'	197.0 - 202.0 rich tar sand as above

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APPENDIX A

(Continued)

CORE INTERVAL (FT)	RECOVERY	DESCRIPTION
		202.0 - 207.0 rich tar sand, grayish black fine grained. Hydrocarbon odor
207.0 - 217.0	100% - 10.0'	207.0 - 217.0 rich tar sand as above yields ashpalt (204.0 - 218.6)
217.0 - 227.0	100% - 10.0'	217.0 - 219.9 tar sand as above
		219.9 - 224.8 marlstone, grayish green
		224.8 - 227.0 tar sand, lt. brown angular sand fragments in bitumin matrix
227.0 - 237.0	100% - 10.0'	227.0 - 232.5 tar sand as above
		232.5 - 234.8 marlstone, grayish green
		234.8 - 237.0 tar sand lt. to dk. brown
237.0 - 247.0 TD	100% - 10.0'	237.0 - 247.0 TD marlstone, grayish green

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APPENDIX B

LITHOLOGIC LOG FOR CORE HOLE NO. 12

ELEVATION: 6746.84
LOCATION: 3788.22N, 2068.89E

DATE: 4/4-6/78
DRILLER: Steve's Drilling
GEOLOGIST: J. Lekas

CORE INTERVAL (FT)	RECOVERY	DESCRIPTION
0 - 9.6		Rotary set 3" steel surface casing
9.6 - 19.6	10.0'	9.6 - 12.0 highly weathered and friable marls & shales
		12.0 - 13.2 good grade oil shale
		13.2 - 15.6 marlstone
		15.6 - 18.2 marlstone with streaks of oil shale
		18.2 - 19.6 low to good grade oil shale
		(19.1 - 19.4) tuff
19.6 - 29.6	10.0'	19.6 - 23.2 good grade oil shale
		23.2 - 24.7 high grade oil shale
		24.7 - 26.4 low grade oil shale
		26.4 - 29.4 marlstone
29.6 - 39.6	10.0'	29.6 - 39.6 marlstone
		(38.55 - 38.8) tuff bed - mahogany marker?
39.6 - 49.6	10.0'	39.6 - 43.0 marlstone
		43.0 - 44.0 low grade oil shale
		44.0 - 45.0 oil saturated tuff
		45.0 - 47.6 low grade oil shale
49.6 - 60.6	10.0'	49.6 - 53.5 high grade oil shale
		53.5 - 56.7 low to good grade oil shale
		56.2 - 57.0 good grade oil shale
		59.0 - 60.6 high grade oil shale

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APPENDIX B

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CORE INTERVAL (FT)	RECOVERY	DESCRIPTION
60.6 - 70.6	9.9'	60.6 - 62.3 low grade oil shale
		62.3 - 62.7 high grade oil shale
		62.7 - 64.7 marlstone with streaks of oil shale
		64.7 - 65.7 high grade oil shale (65.4 - 65.5) tuff
		65.7 - 69.5 salty marlstone with streaks of oil shale
		69.5 - 70.5 low grade oil shale
		(62.6) lumpy tuff with asphalt
70.6 - 80.6	10.0'	70.5 - 74.0 good grade oil shale
		74.0 - 79.0 marlstone with streaks of oil shale, marl grain size increasing with depth
		79.0 - 80.2 high grade oil shale
		80.2 - 80.5 marlstone with streaks of oil shale
		(71.4 - 79.8) tuffs
80.6 - 90.6	10.0'	80.5 - 85.5 marlstone with streaks of oil shale
		(82.4 - 82.5) soft white mineral
		85.5 - 87.0 low to good grade oil shale
		87.0 - 90.5 marlstone
90.6 - 100.6 TD	10.0'	90.5 - 95.0 marlstone
		95.0 - 96.5 good grade oil shale saturated tuff
		96.5 - 100.5 marlstone
		(91.7 - 98) sandy tuff

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APPENDIX C
(CALCULATION OF PERMEABILITY)

```
5!#1 CHR$(27),CHR$(71)
10 REM THIS PROGRAM CALCULATES HYDRAULIC CONDUCTIVITY USING
20 REM THE METHOD DEFINED BY THE BUREAU OF RECLAMATION, (1977)
30 REM BY EDWARD HOYLMAN 5/21/82
40 Q=0\C=0\K=0
50!#1TAB(19),"GEOKINETICS ANGLE HOLE #1"
60!#1
70!#1"TEST NUMBER",TAB(13),"Q (CU.FT./SEC)",TAB(29),"Cu",
80!#1TAB(34),"H (FT.)",TAB(42),"K (M/SEC)",TAB(58),"K (FT./SEC)"
90 !#1
100 READ Z,Q,C,H
110 IF Z=10 THEN GOTO 210
120 IF Z=100 THEN GOTO 270
130 IF Q=0 THEN K=0
140 IF Q=0 THEN K1=0
150 IF Q=0 THEN GOTO 190
160 K=Q/(C*0.125*H) \REM NORTHSTAR BASIC WILL NOT ALLOW A 'Cu' VARIABLE
170 K1=K*0.304
180 REM
190!#1TAB(4),Z,TAB(17),Q,TAB(28),C,TAB(34),H,TAB(41),K1,TAB(57),K
200 GOTO 100
210!#1
220!#1"**************************************************************************"
230 !#1
240!#1TAB(19),"GEOKINETICS CORE HOLE #12"
250!#1
260 GOTO 70
270 !#1
280!#1"**************************************************************************"
290 END
300 DATA 1,.0008,600,899,2,.04,200,209,3,.05,180,246,4,.05,180,145
310 DATA 5,.05,180,137,6,.04,100,83,7,.05,175,75,8,0,0,0,10,0,0,0
320 DATA 1,.002,200,331,2,.0005,250,321,3,0,0,265,4,0,0,209,5,.05,200,199
330 DATA 6,.004,160,166,7,0,0,142,8,0,0,99,9,0,0,0,100,0,0,0
```

GEOKINETICS ANGLE HOLE #1

TEST NUMBER	Q (CU.FT./SEC)	Cu	H (FT.)	K (M/SEC)	K (FT./SEC)
1	.0008	600	899	3.6069706E-09	1.1865035E-08
2	.04	200	209	2.3272727E-06	7.6555024E-06
3	.05	180	246	2.7461608E-06	9.0334237E-06
4	.05	180	145	4.6590037E-06	1.532567E-05
5	.05	180	137	4.9310624E-06	1.62206E-05
6	.04	100	83	1.1720482E-05	3.8554217E-05
7	.05	175	75	9.2647618E-06	3.047619E-05
8	0	0	0	0	0

****

GEOKINETICS CORE HOLE #12

TEST NUMBER	Q (CU.FT./SEC)	Cu	H (FT.)	K (M/SEC)	K (FT./SEC)
1	.002	200	331	7.3474319E-08	2.4169184E-07
2	.0005	250	321	1.5152648E-08	4.9844237E-08
3	0	0	265	0	0
4	0	0	209	0	0
5	.05	200	199	3.0552763E-06	1.0050251E-05
6	.004	160	166	3.6626507E-07	1.2048193E-06
7	0	0	142	0	0
8	0	0	99	0	0
9	0	0	0	0	0

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APPENDIX D

STRUCTURE LOG OF ROCK DISCONTINUITIES GREATER THAN 0.3 FEET, ANGLE HOLE NO. 1

	Internal	Type Discontinuity
RUN 1	10.6-10.8	B
	11.1-11.4	B
	13.8-14.2	B
	14.7-15.6	B
	15.6-15.9	J
	16.9-17.3	B
RUN 2	21.3-22.5	B
	22.5-23.2	B
	23.2-23.9	B
	23.9-24.4	J
	24.7-25.9	J
	26.7-27.2	B
	27.2-27.6	J
RUN 3	28.2-28.8	B
	28.8-29.7	B
	30.3-30.7	B
	31.2-31.8	J
	32.4-33.0	J
	33.0-33.3	B
	34.4-34.8	B
	37.3-37.6	B
	37.6-39.0	B
RUN 4	38.9-39.5	J
	39.5-40.0	B
	40.3-41.3	J
	41.6-42.0	J
	42.4-43.0	B
	45.0-45.5	B
	45.5-45.9	B
	46.4-46.9	B
	46.9-47.5	B
RUN 5	54.6-55.3	B
	55.3-55.7	J
	56.0-56.3	B
	56.3-56.8	B
RUN 6	59.1-59.6	B
	59.6-60.0	J
	61.3-61.7	J
	61.7-62.1	J
	63.3-64.0	B
	64.1-64.5	J
	64.5-65.8	B
	66.6-67.5	B
RUN 7	68.1-68.7	B
	68.9-69.2	B
	70.0-71.2	B
	74.1-74.9	B
	74.9-75.5	B
	76.0-76.5	B
	76.8-77.3	J
RUN 8	78.0-78.4	J
	78.4-78.7	J
	82.3-82.6	B
	84.1-84.5	B
	86.1-86.5	B
RUN 9	88.3-89.3	B
	90.2-90.7	J
	92.2-92.8	J
	93.1-93.4	B
	94.4-94.8	J
	94.8-95.2	J
	95.2-95.6	J
RUN 10	99.6-99.9	J
	99.9-100.3	B
	101.5-102.2	B

Key: J=Discontinuity along joint
B=Discontinuity along bedding surface

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APPENDIX D (Continued)

	Internal	Type Discontinuity
RUN 11		
	107.6-108.2	B
	108.2-108.9	B
	109.5-112.0	B
	112.0-114.2	B
	114.2-115.0	B
	115.0-117.2	B
RUN 12	117.2-119.4	B
	119.4-120.0	B
	12.17-123.3	J
	123.3-123.9	J
	123.9-125.3	J
	124.4-126.1	B
	126.1-126.9	J
RUN 13	127.0-127.9	B
	127.9-129.8	B
	129.9-130.6	B
	130.6-131.4	J
	131.5-132.1	J
	132.1-133.9	B
	133.8-135.7	B
	135.9-136.3	J
	136.3-137.0	B
RUN 14	137.0-138.5	B
	138.5-140.8	B
	140.8-141.4	J
	141.4-142.0	B
	142.0-141.5	B
	141.5-149.0	B
RUN 15	149.1-151.2	B
	151.7-153.2	J
	153.2-157.0	B
RUN 16	157.0-158.1	B
	158.1-158.6	J
	158.6-160.1	J
	160.1-160.8	B
	160.8-161.4	J
	161.4-161.9	J

	Internal	Type Discontinuity
RUN 16		
	161.9-162.8	B
	162.9-163.4	B
	163.4-163.9	B
	163.9-164.5	B
	165.4-166.1	J
	166.5-166.9	B
RUN 17	167.4-168.2	B
	168.4-169.2	J
	169.2=169.9	B
	169.9-170.7	B
	170.8-171.3	B
	171.3-173.4	B
	174.8-175.2	J
	175.2-175.5	B
	175.5-175.9	J
	175.9-176.5	B
	176.5-177.0	B
RUN 18	117.0-177.6	B
	177.6-178.9	B
	179.0-179.7	B
	179.7-180.8	B
	180.8-181.7	B
	181.7-184.2	B
	184.2-187.0	B
RUN 19	187.0-188.1	B
	188.1-190.8	B
	191.0-197.0	B
RUN 20	197.0-200.8	B
	200.8-207.0	B
RUN 21	207.0-217.0	
RUN 22	217.0-225.0	B
	225.3-225.9	B
	225.9-227.0	B
RUN 23	227.0-231.5	B
	231.5-232.4	B
	232.4-235.8	B
	235.8-237.0	B
RUN 24	237.0-247.0	